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**OXYGEN UPTAKE EFFICIENCY SLOPE AND FUNCTIONAL
PHYSICAL PERFORMANCE IN ELDERLY ADULTS**

A Thesis

Submitted to the Graduate Faculty
of the Louisiana State University and
Agricultural and Mechanical College
in partial fulfillment of the
requirements for the degree of
Master of Science

in

The Department of Kinesiology

by

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ABSTRACT

Background: The Oxygen Uptake Efficiency Slope (OUES) attained during submaximal treadmill exercise is a reliable index of cardiorespiratory capacity in older adults. This investigation compares OUES values derived during treadmill walking and performance of the Continuous Scale Physical Function Performance test (CS-PFP). **Method:** A Cosmed portable metabolic cart was used to collect breath gases in 36 older adults (age: 81.8 +/- 7.8 years). Twenty-one subjects performed both the incremental treadmill test and the CS-PFP while an additional 15 subjects performed the CS-PFP, only. **Results:** The regression of log Ventilation vs. VO_2 reveals similar correlations for the CS-PFP and treadmill derived slopes (Rsquare= 0.78-0.93, and 0.81-0.92, respectively). Moreover, the OUES slopes derived from the CS-PFP and treadmill conditions were highly correlated (ICC = .93). **Conclusion:** the OUES can be derived during the performance of the CS-PFP, suggesting an economy of testing whereby physical function and cardiorespiratory capacity can be simultaneously assessed.

CHAPTER 1. INTRODUCTION

The maximal oxygen uptake ($\text{VO}_{2\text{max}}$), defined as the point at which oxygen uptake reaches a plateau despite additional increases in the intensity of work, is regarded as the most valid objective measure of cardiorespiratory capacity. However, deriving values of cardiorespiratory capacity via symptom-limited graded exercise testing is problematic in older adults with significant physical limitations. In these individuals symptom-limited exertion may not be warranted; but moreover, exercise tolerance among older adults may be limited by functional problems other than cardiorespiratory capacity and also relies on patient motivation. Such factors contribute to increased variability and decreased reproducibility of results. Consequently, the assessment of cardiorespiratory capacity from a submaximal testing environment has received recent attention. A recent issue of *The Journal of Gerontology* (2003) was nearly entirely devoted to a discussion of assessing cardiorespiratory in older adults (1). Among the options discussed, is the derivation of the oxygen uptake efficiency slope (OUES).

Baba and coworkers introduced the OUES approach in 1996 as a method for obtaining an index of cardiorespiratory capacity in children with congenital heart defects (2). This approach involves deriving the slope of the semi-log plot of minute ventilation (V_e) vs. oxygen uptake (VO_2). As such, the OUES is an estimation of the efficiency of ventilation with respect to VO_2 , with greater slopes indicating greater ventilatory efficiency. Values of OUES are positively associated with greater cardiorespiratory capacity ($\text{VO}_{2\text{max}}$).

The validity of the OUES as an objective index of cardiorespiratory capacity has undergone testing in several studies. These studies have indicated that the OUES correlates strongly with $\text{VO}_{2\text{max}}$ and is not influenced by exercise intensity. In 2000, Hollenberg and Tager

extended the initial work of Baba et al. by providing evidence that the OUES could be a valid and reliable index of cardiorespiratory capacity in older adults (3). This study employed 998 older adults without clinically recognized cardiovascular disease and a smaller sample (n=12) of older adults with congestive heart failure. Findings indicated that the OUES calculated at 75% of exercise duration differed only 1.9% from the values observed at 100% of exercise duration. OUES also showed a strong positive correlation strongly with VO_{2max} , forced expiratory volume in 1 second, and negative correlation with a history of smoking. Those participants with congestive heart failure also showed significantly lower values of OUES than older participants without cardiovascular disease. In 1999, Baba et al also employed the OUES in the evaluation of adult cardiac patients with chronic heart failure (4). Their findings indicated that the OUES obtained from different levels of exercise agreed and that OUES and VO_{2max} were highly correlated. Additionally, the OUES was able to discriminate effectively between participants according to their New York Heart Association functional class. These findings indicate that the OUES might have clinical diagnostic value in addition to its validity as a measure of cardiorespiratory capacity. Pichon, Jonville, and Denjean reported in 2002 that there were interindividual variations between the VO_{2max} and the OUES despite a significant correlation ($r=0.79$) between the two measures (5). They interpreted their results to mean that the usefulness of the OUES might be limited in clinical practice. However, the study concluded that the OUES still appeared to be the most valid (compared to the VAT) submaximal index of cardiorespiratory reserve and that the OUES could still classify individuals according to their cardiorespiratory capacity. It is important to recognize also that the purpose of the study was to evaluate the interchangeability of the OUES and VO_{2max} . For the purposes of this study, we are investigating the reliability of the OUES in an older population for which symptom-limited and maximal

testing is often contra-indicated. Therefore, the OUES still merits further study and appears to be a useful tool for evaluating cardiorespiratory reserve in populations for whom maximal testing is not warranted.

In using submaximal tests in order to evaluate cardiorespiratory capacity, one problem that arises is the choice of exercise protocol. Ventilatory anaerobic threshold (VAT), which is defined as the oxygen uptake at the onset of lactic acidosis, is an index of aerobic capacity that does not require a maximal effort. However, data indicates that the VAT can be influenced by the particular exercise protocol selected (6). This suggests that the VAT might be subject to limitations due to the lack of reliability in the measurements when different exercise protocols are chosen. Moreover, since the VAT is a subjective measurement, it is subject to inter-evaluator variability. The OUES approach has been tested by Baba et al to determine the agreement in the measure between different exercise protocols (7). This study compared the OUES, VO_{2max} , and VAT during two different treadmill protocols using 16 children and adolescents. Their findings showed that the OUES had good interprotocol agreement, whereas VO_{2max} had less agreement, and the VAT the lowest agreement. This extension of the work testing the reliability of the OUES approach provided further data indicating that the OUES could be used reliably to measure cardiorespiratory function in children in addition to adults and cardiac patients. The investigators chose to use a protocol that reflected the type of intermittent, intense, and short bursts of activity that reflect the type of exercise in which children usually engage. When compared to the OUES observed during the standard incremental Bruce treadmill protocol, the OUES observed did not differ significantly from protocol to protocol and was more reliable than either VO_{2max} or VAT.

While there is substantial evidence that the OUES is a valid objective measure of cardiopulmonary reserve in a wide range of people according to age and health status, there is data suggesting that caution is warranted when using the OUES in an obese population. In 2003, Marinov and Kostianev investigated the exercise tolerance and OUES observed in 60 (30 obese and 30 non-obese) children during incremental treadmill exercise (8). While the OUES was strongly correlated $VO_{2\text{peak}}$ and there was high correlation between OUES at 100% exercise duration and OUES at the anaerobic threshold, the OUES also strongly correlated with the anthropometric variables height and age. In addition, the absolute metabolic cost of exercise and the perceived exertion among the obese were both higher compared to those of normal body weight. The authors concluded that their data showed that the dependence of the OUES on anthropometric variables poses a limitation on its interpretation as an exercise index in childhood. While this study did point out that OUES was correlated to factors other than those directly involved with exercise capacity, the preponderance of evidence from prior work indicates that the OUES is an objective measurement of cardiopulmonary function that does not require a maximal effort.

While the OUES has been correlated to $VO_{2\text{max}}$ and has been shown to be robust to differing exercise protocols and levels of exercise intensity, it is of interest to determine whether the OUES is sensitive enough to detect changes in aerobic exercise capacity due to exercise training. If an individual were to experience an increase in maximal oxygen uptake due to an exercise training program, it would be of interest to determine if the OUES increased in parallel with maximal oxygen uptake. In a 2003 study involving chronic hemodialysis patients, Tsuyuki et al sought to clarify the clinical usefulness of the OUES as a monitoring tool for changes in exercise tolerance and to examine the effects of physical training (9). The results of the study

indicated that the OUES changed significantly in the group that underwent physical training for a period of twenty weeks whereas the OUES did not change in the control group. Moreover, the changes in the OUES correlated positively with those in the maximal oxygen uptake and the anaerobic threshold. These results indicated that the OUES showed utility as a monitoring tool for cardiorespiratory function in the patients selected for the study. In 2004, Mourot et al concluded, however, that the OUES changes in response to endurance training were more variable than $\text{VO}_{2\text{peak}}$, VAT, and power output (10). This study, however, used a smaller sample and a shorter endurance training program (6 weeks) than the one done by Tsuyuki et al. The question of whether or not the OUES is sufficiently sensitive to detect changes in cardiorespiratory functional reserve remains to be clarified, although we might conclude at this stage that the characteristics of the groups studied and the choice of training duration might account for the present variance in the findings.

The OUES is primarily influenced by metabolic acidosis and ventilatory dead space volume, and therefore provides certain advantages. First, this index represents a composite of multiple facets of cardiorespiratory fitness, including pulmonary and cardiac function, as well as oxidative function of skeletal muscle. Second, the OUES slope is not significantly influenced by exercise intensity, thereby rendering it useful for deriving information about cardiorespiratory function from a sub-maximal effort. Third, data also indicate that the OUES is stable across different testing protocols.

While there have been some conflicting reports concerning the interindividual variation in the OUES and one study concluded that the OUES is not interchangeable with $\text{VO}_{2\text{max}}$, there remains significant data to indicate that the OUES remains a useful measure of cardiorespiratory reserve that correlates positively and significantly with $\text{VO}_{2\text{max}}$. The preponderance of the

literature at this stage indicates that the OUES is an objective index of cardiorespiratory capacity that does not require a maximal effort and is free of inter-evaluator variation. Moreover, the OUES appears to be stable across different exercise protocols and age groups of different health status. Taken together, these findings encourage further study of the OUES to extend the validity and use of the measure to new settings.

Exercise testing, whether in a symptom-limited or sub-maximal environment, is typically achieved through incremental treadmill- or cycle-ergometry. However, another modality employed in the older adult population is the “Functional Fitness” test. A number of such tests have been introduced in the past decade or so in an effort to quantify the older adult’s proficiency at performing activities of daily living (ADL). One such test is the continuous-scale physical functional performance test (CS-PFP) developed by Cress (11). This test has been validated against traditional laboratory tests of physical fitness, and is known to be useful for discriminating older adults according to level of dependent-care needs (12). Moreover, this functional test is unique in that it provides the investigator with information about specific aspects of physical fitness thought to influence function (e.g., upper body strength, lower body strength, endurance).

The CS-PFP test is similar to traditional tests of cardiorespiratory fitness in that it requires the participant to perform activities in order of increasing difficulty, culminating in the 6-minute walk. The metabolic requirements of the CS-PFP in a small sample of older adults have been reported, and suggest that the test results in a gradual increase in VO_2 over time, up to a level of approximately $18.5 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ (13). In light of the incremental nature of the CS-PFP, and evidence suggesting that the OUES is stable across incremental test protocols, it can be hypothesized that by performing collection of breath gasses during the CS-PFP, investigators can

acquire information about both functional ability and cardiorespiratory capacity. Such an economy of testing procedures can be of great value to clinicians and scientists as we seek to maximize the information gained through testing procedures.

Therefore, the purpose of the present study is to compare the OUES observed during the CS-PFP to that observed during submaximal treadmill-ergometry in adults over the age of 70. Based on the work of Baba et al., the hypothesis to be tested is that the OUES values obtained during the CS-PFP will compare favorably to those collected during treadmill-ergometry (14). A secondary purpose of the present investigation is to describe the association between the OUES index cardiorespiratory capacity with the functional fitness scores obtained through the CS-PFP. An additional hypothesis is that the OUES will correlate positively with scores observed for the CS-PFP.

CHAPTER 2. METHODS

2.1 Participants

Thirty-six older adults (ages 60-98) participated in this investigation. Fifteen subjects were recruited at random from participants in the population-based *Louisiana Healthy Aging Study* sample, 16 subjects were residents of a retirement community who responded to an invitation to participate in the study, and 5 participants were recruited from a community-based physical activity program for low-income seniors. All subjects were required to be free of overt symptoms of cardiovascular disease, and were not otherwise deemed to be at high risk for adverse responses to exercise according to the American College of Sports Medicine Guidelines for Exercise Testing and Prescription (15).

2.2 Study Design

This was an observational study with a crossover subcomponent. The institutional review boards of Louisiana State University, the Louisiana State University Health Sciences Center, and The Pennington Biomedical Research Center approved all procedures described herein. Informed consent was obtained prior to participation. After collection of demographic data and a medical history, subjects that agreed to participate in the crossover component were randomized to undergo CS-PFP or treadmill testing on day one followed by the alternative test 48 hours later. The remainder of the subjects was only assessed with the CS-PFP. All subjects were simultaneously monitored for breath gas analysis.

2.3 Procedures

Immediately prior to testing, the investigator described the testing protocol in detail. A Cosmed K4b² breath gas analyzer (Milan, Italy) was placed on the participant's torso and the spirometer and gas collection mask fixed to the participant's face. A *Polar* heart rate monitor

was also placed on the participants torso to obtain heart rate data. Breath gases were collected on a breath-by-breath basis and continuous heart rate data were collected throughout the performance of the testing protocols.

All subjects performed the CS-PFP10 physical function performance test. This test requires the participant to perform activities thought to be important for living independently. The test includes carrying a pot of self-selected weight from one counter to another, putting on and taking off a jacket, picking up scarves off the floor, a vertical reach test, sweeping cat litter off a floor, transferring laundry to and from a washer and dryer, getting down on the floor and returning to a standing position, carrying groceries up a bus platform, ascending a flight of stairs, and a 6-minute walk. The items are performed in increasing difficulty. Raw scores for each item are converted to a continuous scale from 0-100, and averaged to yield a total PFP score, and several subscales. The CS-PFP is described in detail in Cress (11) and can be found on the CS-PFP website (http://www.coe.uga.edu/cs-pfp/cspfp_test.html) (16).

A subset of subjects also performed an incremental sub-maximal treadmill test. The K4b² portable breath gas analyzer, and the *Polar* heart rate monitor were also applied during treadmill testing, and a *Precor* 6.2 motor-driven treadmill was employed. The treadmill protocol required the subjects to perform a modified version of the USAF protocol (15). The protocol allowed the participant to self-select a comfortable walking speed. The incline was initially set at 0% and was increased by 5% every 3 minutes while the speed was left constant. The test was terminated when the participant reported a rating of perceived exertion > 15 on the Borg 20 point scale (15).

2.4 Oxygen Uptake Efficiency Slope Derivation

The breath-by-breath gas data collected during the CS-PFP and the treadmill exam were averaged over every 15 seconds. With respect to the CS-PFP condition, the log of minute

ventilation ($\log V_E$) was plotted against VO_2 for all data points collected throughout the test, and the calculated slope is the ($OUES_{PFP}$) (See figure 1a). The Treadmill data were treated according to the procedures detailed by Baba et al (2), and Hollenberg and Tager (3). In short, the $\log V_E$ and VO_2 observed during each stage were used to derive the slope (i.e. $OUES_{TM}$) (see figure 1b).

2.5 Statistical Analysis

All statistical analyses were performed using SPSS 11.0 for Windows. For each case and condition, linear regression and Pearson correlation coefficients were derived in order to describe the $OUES$ ($\log V_E$ vs. VO_2) slopes. Dependent t-tests were used to examine differences in the cardiorespiratory responses to the CS-PFP and submaximal treadmill within the nine cases where both tests were performed. ANOVA was used to generate intraclass correlation coefficients for the purpose of comparing the $OUES_{PFP}$ to the $OUES_{TM}$. Pearson correlation coefficients were also derived for the purpose of exploring the relationships between $OUES_{PFP}$ and CS-PFP total scores for all 19 participants. Alpha was set a-priori at $p < 0.05$.

CHAPTER 3. RESULTS

Table 1 provides descriptive statistics for the twenty-one participants who underwent both CS-PFP and submaximal treadmill testing, as well as for the 15 additional participants who underwent CS-PFP testing only.

Table 1. Participant Characteristics

	<i>TM and CS-PFP</i>		<i>CS-PFP only</i>	
N	21 (12 female, 9 male)		15 (9 female, 6 male)	
	Mean	s.d.	Mean	s.d.
Age	81.8	7.8	84.6	7.9
Height (cm)	173.6	10.1	167.3	11.6
Weight (kg)	74.6	8.2	72.3	11.4
BMI	23.6	2.4	24.8	4.2
CS-PFP total	38.6	12.8	29.9	12.0

Figures 1a and 1b illustrate the behavior of the OUES data in a 95 year-old female participant during the CS-PFP and treadmill exams, respectively.

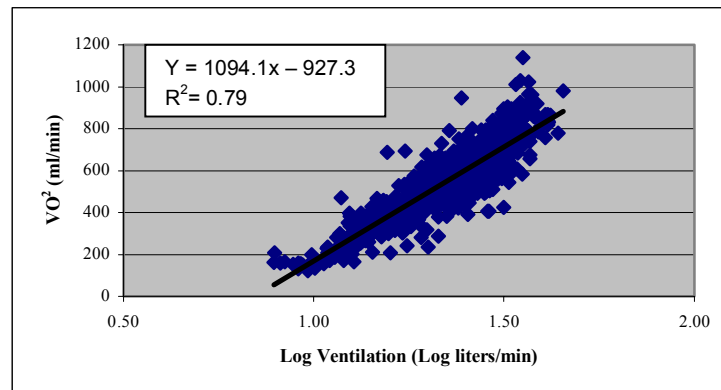


Figure 1(a). OUES_{PFP}

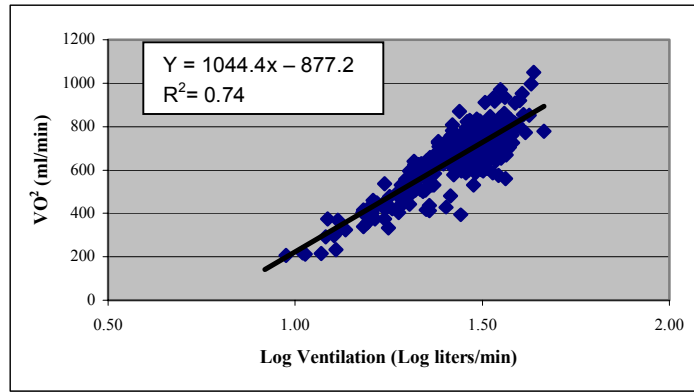


Figure 1(b). OUES_{TM}

Table 2 provides a comparison of cardiorespiratory parameters as observed prior to and during the performance of the CS-PFP and submaximal treadmill tests.

Table 2. Cardiorespiratory Parameters during Treadmill and CS-PFP

	<i>Treadmill</i>		<i>CS-PFP</i>	
	Mean	s.d.	Mean	s.d.
Rest VO_2 ($\text{ml kg}^{-1} \cdot \text{min}^{-1}$)	3.7	0.4	3.7	0.3
Rest V_E ($\text{L} \cdot \text{min}^{-1}$)	11.6	2.1	11.1	1.1
Peak VO_2 ($\text{ml kg}^{-1} \cdot \text{min}^{-1}$)	19.6	8.2	19.0	7.7
Peak V_E ($\text{L} \cdot \text{min}^{-1}$)	63.6	26.5	60.9	20.2
Rest HR (bpm)	76.6	9.0	75.8	8.1
Peak HR (bpm)	133.7	29.3	135.5	34.2
OUES slope	2061.4	672.2	1944.1	585.2
OUES R^2	0.87	0.06	0.86	0.05
OUES _{6 min walk}			2052.5	682.6

T-tests revealed no statistically significant differences between the cardiorespiratory responses, although peak V_E and peak VO_2 tended to be slightly lower during the CS-PFP condition. Repeated measures ANOVA on $OUES_{PFP}$ vs. $OUES_{TM}$ values revealed an intraclass correlation coefficient of 0.93, suggesting good agreement between the two approaches. Furthermore, inspection of the correlation coefficients for the OUES data (i.e., $\log V_e$ vs. VO_2) (see Table 2) suggests a comparable strength of association between $\log V_E$ and VO_2 across test conditions. Finally, Pearson correlation revealed a strong association between $OUES_{PFP}$ and total CS-PFP scores ($r = 0.74$, $p < 0.01$), indicating that approximately 50% of the variance in physical functional performance can be explained by individual differences in cardiorespiratory fitness.

CHAPTER 4. DISCUSSION

The primary purpose of this investigation was to compare the oxygen uptake efficiency slopes observed during the performance of a physical function test battery (i.e., the CS-PFP) and during incremental submaximal treadmill walking in older adults. The participants in this investigation represent a wide age-range of relatively healthy older adults insofar as none of the participants had any overt symptoms of cardiorespiratory diseases, nor did they have any other contraindications for exercise. Furthermore, all of the participants scored at least 25 on the mini mental status exam (data not shown), suggesting that none were suffering from any serious cognitive deficit. Therefore, it may not be prudent to extend the findings of this investigation to older adults with significant physical or mental health problems.

The peak VO_2s obtained during the CS-PFP are similar to those previously reported (13). The CS-PFP total scores and standard deviations, while in the range of expected values (11,12), are somewhat low and may reflect the somewhat advanced mean age of the participants. The data demonstrate good agreement between the oxygen uptake efficiency slopes scores derived during the CS-PFP and the sub-maximal treadmill protocol. Further, the slopes derived during the CS-PFP are significantly associated with CS-PFP scores. Thus, the results of the present investigation extend the work of Hollenberg & Tager (3) in such a way as to suggest that the oxygen uptake efficiency slope is attainable during the performance of the CS-PFP physical functional performance test.

The present study also expands the scope of work done in evaluating the reliability and inter-protocol agreement of the OUES. Baba et. al. previously evaluated the interprotocol agreement of the OUES in a pediatric population (7) by comparing the OUES observed during maximal

incremental treadmill exercise versus that observed during a rapidly increasing staged protocol (RIS). The RIS appeared to more accurately represent the activities of children than standard incremental protocols and was therefore of interest as a comparison protocol by which to evaluate the reliability of the OUES. The present study extends the investigation of the reliability of the OUES as it pertains to older adults. Baba et. al. found that the OUES showed good inter-protocol agreement in the pediatric population (7). The present study indicates that the OUES appears also to be reproducible in a population of older adults when comparing the OUES observed during sub-maximal incremental treadmill exercise to that observed during a functional physical test that mimics activities of daily living.

This is important to the clinician in that it offers an opportunity for an increase in the economy of testing. By collecting breath gases during the performance of the CS-PFP the clinician can gain information about both the physical functional competence and physiologic capacity of the older adult.

An important limitation of this study, and limitation to the application of the submaximal-testing paradigm in general, is that achievement of ‘moderate’ intensity work is assumed. In the present study an RPE of > 15 was used as an operational definition of moderate intensity of work. Recent data from Pichon et. al. (5) describe the extent to which the oxygen uptake efficiency slope is systematically influenced by the relative intensity achieved during incremental walking. Their data indicate that the logarithmic transformation of minute-ventilation does not entirely account for the non-linearity of the ventilatory response to incremental work. This suggests that the applicability of the submaximal derivation of oxygen uptake efficiency as an index of cardiorespiratory capacity is, at present, somewhat limited. However, some preliminary data from a study at Louisiana State University indicate that the OUES showed only small intra-

individual variation when calculated at 65% of exercise duration compared to 100% of exercise duration (see appendix). The data from this study reflected the homogeneity of the fitness levels in the study participants. This preliminary data suggests that the OUES has predictive validity for $\text{VO}_{2\text{max}}$ in young healthy subjects with similar fitness levels. The data implies that the use of subclasses of population would probably be critical in attempt to extend the use of OUES calculated during sub-maximal exercises as a method to calculate the $\text{VO}_{2\text{max}}$.

The findings of Pichon et. al. (5) also suggest that there is inter-individual variation in the differences between the OUES and $\text{VO}_{2\text{max}}$. They concluded based on this that the OUES cannot predict maximal aerobic power. Their study was designed to evaluate whether or not the OUES and $\text{VO}_{2\text{max}}$ are interchangeable. Their data suggests that the two measures are not interchangeable. However, they concluded that the OUES was useful in classifying individuals according to aerobic fitness. Moreover, they compared the agreement between $\text{VO}_{2\text{max}}$ and other sub-maximal indexes widely used in clinical practice and found that the OUES showed better limits of agreement with $\text{VO}_{2\text{max}}$ than the VAT. This is in agreement with the findings of Baba et. al., which suggested that the OUES provided an objective index of cardiorespiratory fitness superior to other sub-maximal indexes (2). Taken together, these findings of earlier studies indicate that the OUES appears to be the most valid and reliable index of aerobic fitness that can be derived from a sub-maximal effort. While Pichon et. al. concluded that the lack of interchangeability between the OUES and $\text{VO}_{2\text{max}}$ might limit its use in clinical practice, it is important to recognize that the OUES remains an attractive means of measuring aerobic fitness in populations for whom maximal or symptom-limited exertion is not warranted.

Data from Hollenberg and Tager (3) also raises the concern that $\text{VO}_2 \text{ max}$ itself is subject to considerable day-to-day intra-individual variation in the older adult population. In contrast to the

somewhat predictable, systematic nature of the intra-individual variation in oxygen uptake efficiency, it appears that the intra-individual variability in $\text{VO}_{2\text{max}}$ in older adults is random. Therefore, continued refinement of the techniques for deriving oxygen uptake efficiency certainly appears to provide clinicians and scientists with opportunity for acquiring a more stable measure of cardiorespiratory capacity in older adults than is presently available.

Despite the limitations associated with using the oxygen uptake efficiency slope as index of cardiorespiratory capacity, the data from the present investigation provide construct validity for its application in the functional-fitness testing environment. The correlation between PFP total scores and oxygen uptake efficiency during the CS-PFP ($r = .76, p < .01$) are in close agreement with previous reports of the degree of association between $\text{VO}_{2\text{max}}$ and PFP total scores (11) and are consistent with recent data from Alexander et al. (1) who demonstrated that oxygen uptake kinetics differed between groups of elders based on presence or absence of functional impairment.

In summary, the results of this study suggest that: a) the oxygen uptake efficiency slope can be derived during a functional fitness test, thereby providing clinicians and scientists with an opportunity for an economy of testing; and b) oxygen uptake efficiency is closely associated with physical function, explaining as much as 50% of the variation in functional fitness score, even among a relatively homogenous sample of older adults. Future efforts should take aim at reducing systematic variability associated with the influence of relative work intensity on the slope of oxygen uptake efficiency.

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APPENDIX

VALIDITY OF OUES AS A FUNCTION OF PERCENT RELATIVE EFFORT

Introduction

Maximal oxygen uptake ($\text{VO}_{2\text{max}}$) is considered the most reliable index of overall exercise capacity in healthy people, and of cardiorespiratory functional reserve in older people and patients with chronic heart failure. However, this value is greatly influenced by the intensity of exercise and therefore requires a maximal effort of subjects. Thus, the assessment of $\text{VO}_{2\text{max}}$ is of questionable value when applied to the study of older people or subjects with various disease states.

The Oxygen Uptake Efficiency Slope (OUES) reflects the relationship between oxygen uptake (VO_2 in ml/min) and total ventilation (VE in L/min), and it is best described by a single exponential function in almost all subjects (Baba, 1996). Recently, Hollenberg and Tager (2000), using a treadmill test, demonstrated that the OUES is an objective index of exercise performance and cardiopulmonary reserve that does not require a maximal exercise effort, finding no significant differences between OUES calculated at different exercise durations. However, the minimal intensity required to yield a valid and reliable index of the cardiorespiratory function is still unclear. Our purpose was to quantify the OUES variability and reliability at different intensities, expressed as a percentage of $\text{VO}_{2\text{max}}$, and describe the predictive validity of OUES as a function of percent relative effort.

Methods

Subjects: 15 men and 14 women, healthy, with an age ranging from 19 to 37 (mean 23.3 ± 4.7). All subjects were normally active, and none of them were habitual smokers. All subjects gave their written informed consent for participation in this study.

Test: The incremental maximal exercise test performed in a Monark 818E cycle-ergometer. The test was composed of 3 minutes of unloaded pedalling, followed by an incremental increase in power output (30W x 1') until a maximum effort was achieved as defined by meeting two of the three following criteria: Plateau in VO_2 , $\text{RQ} > 1.15$, and failure to maintain pedal frequency. Breath by breath gas analysis was performed during the tests, and 10 seconds average values were used for all calculations. $\text{VO}_{2\text{max}}$ (or $\text{VO}_{2\text{peak}}$) was determined. Oxygen uptake during exercise (from the beginning of the loaded pedalling to the end of the exercise) was plotted against the logarithm of ventilation (x- and y-axis respectively). The OUES was calculated as the slope of the simple linear regression between these two variables.

Statistics: The results are expressed as the mean value \pm SD, and alpha was set at $p < .05$. Simple linear regression was used to calculate the OUES. The relationship between the OUES (x-axis) and the $\text{VO}_{2\text{max}}$ values (y-axis) at different levels of exercise intensity were also assessed by linear regression analysis. Agreement between the OUES measurement obtained at different levels of exercise intensity was assessed by intraclass correlation coefficient (ICC). The method of Bland and Altman (Bland and Altman, 1986) was used to assess the agreement between measured $\text{VO}_{2\text{max}}$ and $\text{VO}_{2\text{max}}$ predicted from OUES at 100-85-75 and 65%.

Results

The regression line of the $\text{VO}_{2\text{max}}$ (y-axis) plotted versus the OUES (x-axis), showed a small progressive increase from 100% to 50% of $\text{VO}_{2\text{max}}$ intensity. In particular, the OUES at 65% of $\text{VO}_{2\text{max}}$ only differed of 7.0% from the OUES at 100% $\text{VO}_{2\text{max}}$. Intraclass Correlation coefficients (ICC) show strong agreement between the values of OUES at 100% of $\text{VO}_{2\text{max}}$ and

that calculated at lower intensities. OUES also appears to provide a good average estimation of VO_2max , but with lower intensity of exercise (% VO_2max) we observed a wider variability of the data (maximum average difference $2.5 \pm 14.2\%$ at 60% of VO_2max , difference at 100% of VO_2max $2.3 \pm 9.9\%$). BLAND AND ALTMAN ANALYSIS The mean difference of VO_2max calculated from OUES was $+0.4 \pm 3.4$ (100%), -0.3 ± 4.0 (85%), -1.3 ± 4.2 (75%) and -2.2 ± 4.7 $\text{mlO}_2/\text{kg}/\text{min}$. The upper and lower limits of agreement calculated as: $d \pm (-1.96 \times \text{SD})$, where $+7.2$ and -6.3 (100%), $+8.3$ and -7.6 (85%), $+8.5$ and -7.8 (75%), $+9.4$ and -8.5 $\text{ml O}_2/\text{kg}/\text{min}$ (65%), respectively.

Discussion

Our data confirm that the OUES, derived at sub-maximal intensities of exercise, provides a reliable index of cardiorespiratory function in young moderately active subjects. Indeed, the OUES calculated at different intensities maintains a high reliability with respect to the OUES calculated at 100%, with an intensity of 65% that still present a good intraindividual correlation (ICC range 0.8464 – 0.9635). These results appear similar to that of Hollenberg & Tager (2000); however, the present data, being very specific to the intensity of exercise, extend the results of Hollenberg and Tager whose inferences are somewhat limited in that they are specific to duration of the Bruce treadmill protocol. The strong reliability of these data, suggests the idea of using the OUES as a method to calculate the VO_2max without performing a maximal test. In a recent study, Pichon et al. (November 2002) tried to evaluate the interchangeability of these two indexes by comparing VO_2max predicted from OUES to VO_2max measured with a treadmill test. They concluded that, although OUES and VO_2max were significantly correlated ($r = 0.79$), the wide inter-individual variations may limit the usefulness of OUES in clinical practice. The

lower variability observed in our data may reflect a potential greater homogeneity of fitness level among our subjects, suggesting that the use of subclasses of population would probably be critical in attempt to extend the use of OUES calculated during sub-maximal exercises as a method to calculate the $VO_{2\max}$.

In conclusion, even though the OUES confirmed to be a good index of cardiorespiratory function that is not greatly influenced by the exercise intensity, we believe that the OUES may improve its ability to assess the fitness level when used in populations where equations have been specifically developed, thus reducing the large inter-individual variability.

VITA

Scott Fuller was born in Beaumont, Texas on June 29, 1970. He graduated from Taipei American School in Taipei, Taiwan, Republic of China in 1988. He received his Bachelor of Arts in History from Louisiana State University in 1993. He then served as a teaching intern in the Social Studies Department at the International School of Amsterdam in the Netherlands before returning to LSU for graduate school. After receiving his Masters in Public Administration from LSU in 1998, he then taught English in Okinawa, Japan. He will receive his Master of Science in Kinesiology from LSU in December 2004. He currently resides in Tucson, Arizona with his wife Claudia and works as a volunteer assistant coach with the University of Arizona men's tennis team.